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An automatic shot-change detector for telecine

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AN AUTOMATIC SHOT-CHANGE DETECTOR FOR TELEVISION

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1. Introduction

In order to reduce the visibility of scene to scene colour and exposure errors which can arise when colour film is reproduced by telecine, it has been common practice for many years to correct for these changes by manual operation of a colour corrector, such as Tarif,[1] when the changes are observed. This method is satisfactory provided a well graded print is available, since scene to scene colour exposure variations are then small. If 'camera original' reversal, colour negative,[2] or 'one light' prints (all of which can have large shot to shot variations) form a significant proportion of a film programme, then it is advantageous to be able to pre-programme colour and exposure error-correction settings. Corrections determined during rehersal of the film may then be introduced when the film is broadcast at the beginning of each shot, rather than gradually (and visibly) by an operator.[3]

An essential piece of information required is the location in the film of each shot change so that the new correction can be introduced in the field-blanking interval between shots. In the BBC designed pre-programming equipment the locations of scene changes in a film can be indicated in several ways, including the preparation of a 'frame-cue tape'; this is a record, on paper tape, of the film frame numbers at which scene changes occur. The preparation of this tape involves visual inspection of the film either in the telecine itself or on a modified editing bench, and since the film must be stopped at each shot change this procedure can take a considerable time. A more satisfactory method is to add metal cue-dots to the edge of the film during the editing operation; these dots can be detected as the film runs in the telecine and a control pulse fed to the programming equipment to indicate that a shot change has occurred. Although cue-dotting is better than making a separate frame-cue tape, since the film does not have to be handled twice (which increases the risk of it picking up dirt), the editing operation takes slightly longer and advance notice of pre-programming is required at the editing stage. This report describes a detector capable of recognising shot changes as the film runs in the telecine and feeding control pulses to the programmer, enabling pre-programming to be carried out with very little extra work.

No detector so far envisaged can detect dissolves or fades, but fortunately these are not always present in significant numbers in conventionally printed films and are never present in films assembled from camera original reversal or negative films. It is these types of film which are most likely to benefit from pre-programmed corrections, since they involve no printing operation in which colour grading can be carried out.

2. Possible systems

Several different methods of detecting shot changes were considered.

2.1. Physical detection of a splice

This was ruled out since printed films would produce no indications and the system would be unduly sensitive to critical mechanical adjustment and film damage.

2.2. Change of mean brightness and/or colour

A prototype system which integrated the Y, R–Y, B–Y signals over each field period, and compared the results from successive fields was built and tested.

Since a shot change is not necessarily accompanied by a change in mean brightness or colour larger than that normally produced by motion of the camera or scene, the adjustment of the detector proved to be a critical compromise between missed shot changes (when the sensitivity was too low) and false indications (when the sensitivity was too high). The performance depended on the programme content and, when tested with a large variety of material, the detector, on average, missed approximately 20% of all shot changes and gave 10% false indications. This performance was not considered adequate since, with some films the detector made more mistakes (either misses or false indications) than correct indications.

2.3. Sudden change of picture detail[4]

The method finally adopted is based on a comparison of video signals derived from successive film frames. This is achieved by delaying video signals for one television field (20 ms) duration so that information from two successive fields is continuously available for comparison.* This comparison could be made by deriving the correlation function (as described below) but since this would have been complicated to instrument the simpler method of subtraction is in fact used. A simple form of detector thus registers a shot change when the comparison of successive fields shows a significant change in detail content. This is the basic principle on which the detector operates, but protection against spurious indications due to normal movement in the scene is also provided (see Section 4).

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* This is only possible if the telecine machine is locked at 25 film frames per second to the synchronising pulses of a 50 fields per second television system, so that each complete film frame is scanned in exactly two television fields.

2.3.1. Correlation

The video signals appearing at the input and output of a 20 ms video delay may be represented as functions of time $x(t)$ and $y(t)$ respectively, thus $x(t) = y(t + T)$ where T is the delay time of the delay line (20 ms). If $x(t)$ and $y(t)$ are only considered over the range $T_1 < t < T_2$, where the time T_1 and T_2 represent the beginning and end of the active field of the television waveform, then $x(t)$ and $y(t)$ represent the video signals of two consecutive fields which are now available simultaneously.

The degree of similarity of the two fields may be found by evaluating the correlation of $x(t)$ and $y(t)$ over the period T_1 to T_2. This correlation may be expressed as the correlation coefficient r of $x(t)$ and $y(t)$:

$$\text{where } r = \frac{\int_{T_1}^{T_2} \left[x(t) - \bar{x}\right] . \left[y(t) - \bar{y}\right] dt}{\left(\int_{T_1}^{T_2} \left[x(t) - \bar{x}\right]^2 dt . \int_{T_1}^{T_2} \left[y(t) - \bar{y}\right]^2 dt\right)^{1/2}}$$

In this expression $\bar{x}$ and $\bar{y}$ represent the mean of $x(t)$ and $y(t)$ respectively. In practice the terms $[x(t) - \bar{x}]$ and $[y(t) - \bar{y}]$ may be approximated by a.c. coupling the input signals $x(t)$ and $y(t)$ to remove their d.c. components; the time constant of the coupling circuit should be less than a field period. If the a.c. coupled input signals are $x'(t)$ and $y'(t)$ the modified correlation coefficient r$'$ may be defined:

$$r' = \frac{\int_{T_1}^{T_2} \left[x'(t) \;.\; y'(t)\right] dt}{\left(\int_{T_1}^{T_2} \left[x'(t)\right]^2 dt . \int_{T_1}^{T_2} \left[y'(t)\right]^2 dt\right)^{1/2}}$$

A simplified schematic diagram of a correlator to generate the above function is shown in Fig. 1. In order to correlate over the active field period all the integrators shown in Fig. 1 must be set to zero at the beginning of the active field (at T_1), and the output of the correlator sampled at the end of the active field (at T_2).

The degree of similarity of the two fields is determined by measuring the correlation coefficient. If the two fields are identical, i.e. $x(t) = y(t)$ then the correlation coefficient is unity. Two dissimilar fields produce a correlation of smaller magnitude.

The output of the correlator can be sampled at the end of each active field period, the correlation coefficient obtained, and applied to a level detector. If the threshold of the level detector is set to a value less than unity a shot change is indicated when the input to the level detector is less than the threshold. Although the generation of the correlation coefficient is the ideal form of comparison, it will be seen from Fig. 1 that the instrumentation is complicated since it requires several multipliers and integrators. A simpler alternative was therefore sought.

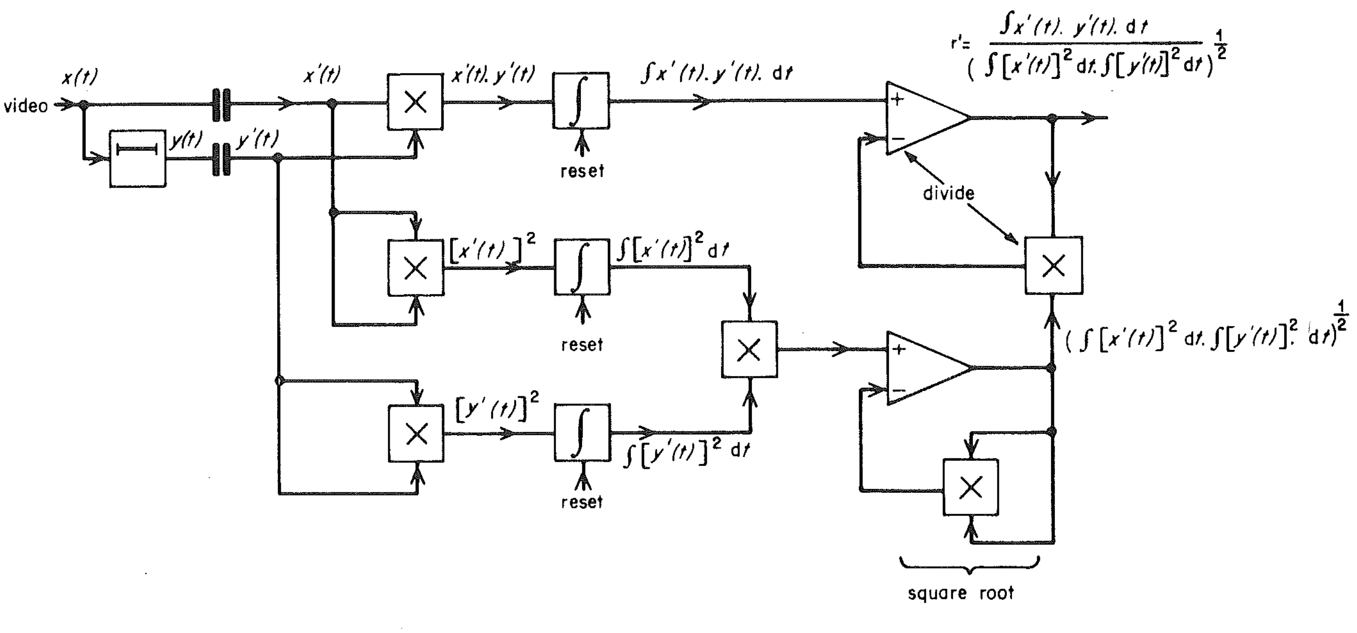

Fig. 1 - Comparison by correlation - block diagram

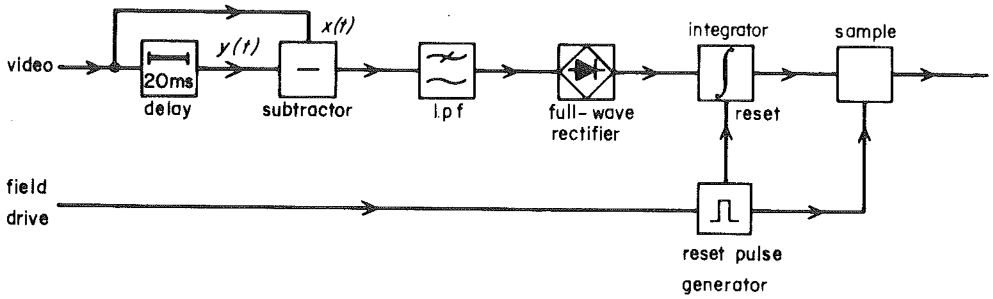

Fig. 2 - Comparison by subtraction - block diagram

2.3.2. Subtraction

A simplified block diagram of the comparator finally used is shown in Fig. 2. One field of video signal is stored in a 20 ms delay and compared with the next field by subtracting the undelayed video signal from it. Any difference between the two fields appears at the subtractor output and may be used to recognise shot changes.

High-frequency difference components which may be generated by slow movement of detail within the scene are removed by a low-pass filter. The bandwidth of this filter is a compromise between reducing the unwanted effects of motion and removing difference information which would aid in the recognition of a shot change. A bandwidth of 200 Hz has been found to be suitable but, even with this low bandwidth, very rapid motion can still give rise to larger differences than sometimes occur at real shot changes. This difficulty is overcome by the protection circuits described in Section 4.

The low-bandwidth difference signal is full-wave rectified and integrated over a field period. At the end of each field period the integrator output is sampled and the integrator reset to zero ready for the next field.

The sampled integrator output represents the total low-bandwidth difference between successive fields and a shot change may be indicated if this exceeds a certain level.

If $y(t)$ and $x(t)$ represent the delayed and undelayed signals:

$$\text{Integrator Output} = \int_{T_1}^{T_2} \left| \int_{-\infty}^{+\infty} \Big[y(t-\tau) - x(t-\tau) \Big] \gamma(\tau) \,.\, d\tau \right| dt$$

(where T_1 and T_2 represent the limits of the active field and $\gamma(\tau)$ is the impulse response of the low-pass filter).

This method of comparison is mathematically less elegant than correlation, but it is simple to instrument and has been found to work sufficiently well to make the added complication of correlation unnecessary.

3. The field delay

A delay of 20 ms for a full-bandwidth video signal is both very elaborate and expensive. Fortunately, since the output is to be low-pass filtered, the delay need only be capable of passing a 200 Hz bandwidth signal and a great reduction of cost and complexity is possible.

Mechanical or acoustic delay lines could be used to provide a delay of 20 ms with a bandwidth of 200 Hz, however, a more compact electronic delay can be constructed if the signal is encoded into a train of binary pulses which may be stored in a shift register. The incoming video is encoded into binary form by a process known as Delta-Sigma Modulation ($\Delta\Sigma$ Mod.) and a 1024 stage shift register clocked at 51·2 KHz provides the required 20 ms delay between input and output.

Delta-Sigma Modulation has the advantage that both coding and decoding are extremely simple to instrument. The coder (shown in Fig. 3) produces a train of binary pulses whose mean level is equal to that of the input signal. The output pulses are subtracted from the input and the difference integrated to determine the mean error. The polarity of this error is used to control the polarity of the next output pulse so that the error is continuously minimised. The coded signal may be simply decoded by a low-pass filter to remove the clock frequency components and leave low-bandwidth mean level information. In the complete comparator (shown as part of Fig. 4) the coded

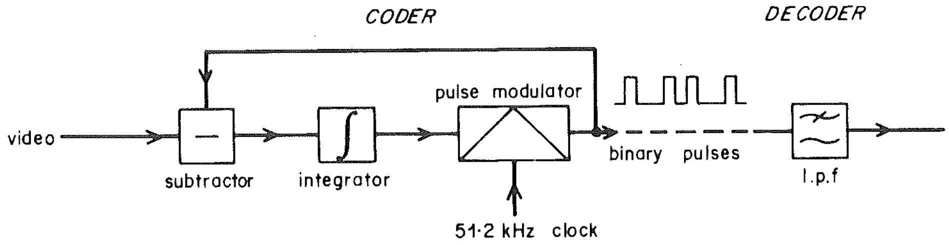

Fig. 3 - $\Delta\Sigma$ Modulation - block diagram

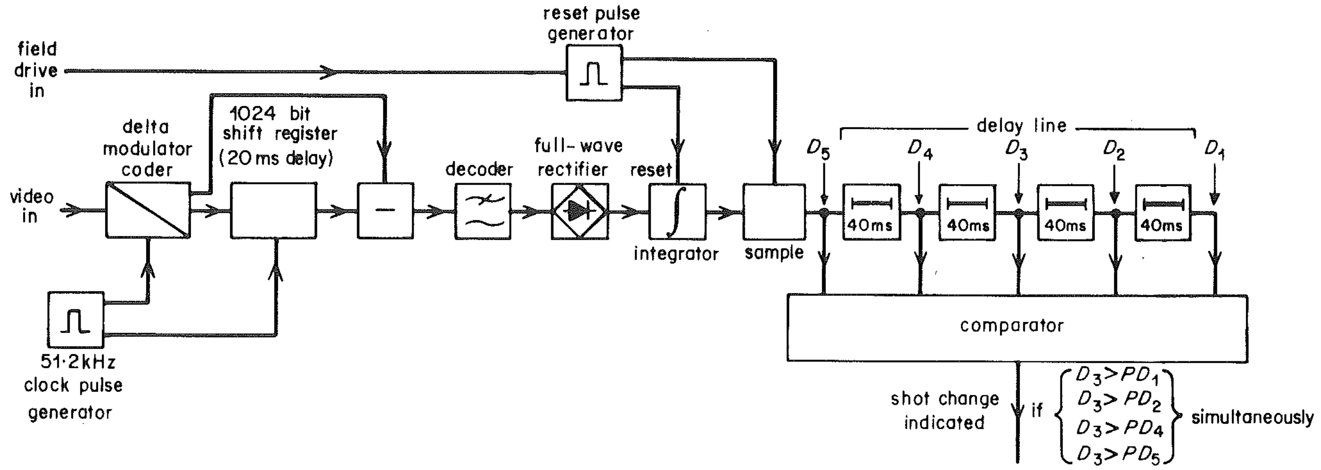

Fig. 4 - Shot change detector - block diagram

input pulses are subtracted from the delayed pulses and the low-pass filter serves the dual function of decoding the ΔΣ Modulation and restricting the bandwidth of the difference signal to 200 Hz. The signal-to-noise ratio depends on the ratio of clock rate to filter bandwidth. With a 51·2 KHz clock and a 200 Hz filter the peak signal to peak quantising noise ratio is approximately 50 dB which is ample.

4. The detector

Fig. 4 shows a simplified block diagram of the complete shot-change detector incorporating 'movement protection' which will be explained in Section 4.1. The video input is band limited and coded into serial binary form by the delta modulator using a sampling frequency of 51·2 KHz. The resulting train of binary digits is then delayed in a 1024 bit M.O.S. shift register, also clocked at 51·2 KHz, to provide a 20 ms delay. Comparison of information from successive fields is achieved by subtracting the undelayed bit stream from the delayed version, the resulting output being decoded by a low-pass filter to produce a low-frequency difference signal; this difference signal is then rectified and integrated over a field period. At the end of each field the integrated signal is sampled and the integrator re-set. This sampled output thus represents the difference between successive fields.

The 'ideal' shot change which is most easily detected is that in which successive film frames describe radically different stationary scenes. Fig. 5 shows waveforms associated with such an 'ideal' shot change. Fig. 5(*a*) shows the low-pass filtered video signal associated with three film frames either side of a shot change. Fig. 5(*b*) shows the video difference signal between successive fields and Fig. 5(*c*) the integrator output. (It should be noted that due to a D.C. offset at the input to the integrator there is a constant output with no video difference signal input; this is instrumental and should be ignored.) The integrator output associated with such a shot-change may easily be detected by means of a monostable which is triggered by pulses that exceed a pre-determined magnitude. Some discrimination against movement producing sufficient integrator output to indicate a spurious shot change can be provided by a suitable choice of the minimum magnitude of the integrator output necessary to trigger the monostable. This method is, however, most unsatisfactory and either results in insufficient movement protection or lack of sensitivity causing many true shot changes to be missed.

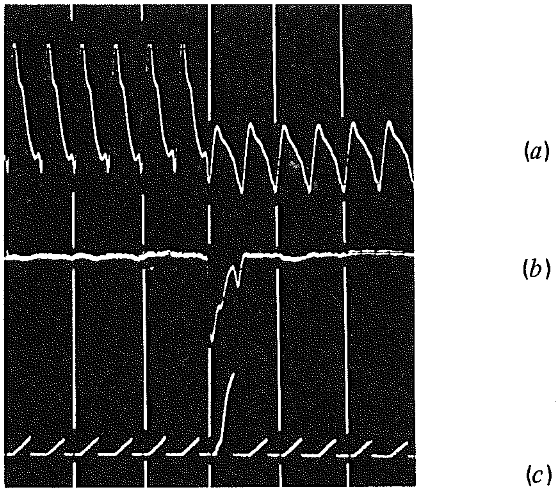

Fig. 5 - Ideal shot change

(*a*) Filtered video input (*b*) Difference between fields

(*c*) Integrated (rectified) difference (reset during blanking)

A very much more satisfactory method is to examine the integrator output for single pulses which are produced at shot changes, so that a succession of pulses on alternate fields which will be produced by scene or camera movement may be ignored.

4.1. Movement protection

Fig. 6(*a*) shows a typical video signal resulting from steady motion in the picture with no shot change. Fig. 6(*b*) shows the resulting difference signal from eight successive film frames and Fig. 6(*c*) shows the integrated, rectified difference signals. It will be seen that Fig. 5(*c*) and Fig. 6(*c*) waveforms would both operate a simple output-level

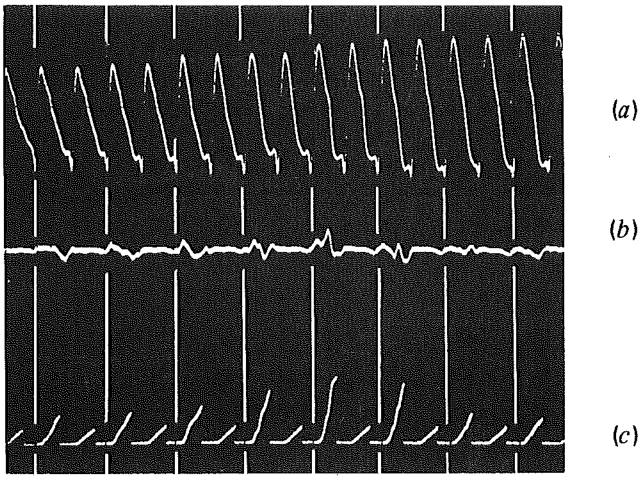

Fig. 6 - The effect of motion
(*a*) Filtered video input (*b*) Difference between fields
(*c*) Integrated (rectified) difference

detector, but that the output at Fig. 6(*c*) contains a succession of pulses whereas the output in Fig. 5(*c*) is unique. Thus movement can be discriminated against by examining the integrator output for unique changes.

In order to do this it is necessary to store integrator outputs over several successive film frames and to compare them. It has been found experimentally that five frames is a suitable choice and that a shot change should only be indicated if any integrator output is greater than that from the two preceeding and two succeeding frames by a factor P. If this factor P is too large, shot changes during even moderate movement will not be indicated. If it is too small, there will be insufficient movement protection, particularly for movement involving high rates of acceleration. The optimum value was determined by experiment involving the examination of a great deal of film, since different types of film, for example, hand held camera shots and static scenic subject matter, represent the extremes which must be dealt with. Although the final choice must be a compromise, a value of 2·0 for the factor P was found to be suitable and provides quite remarkable protection against movement without resulting in a serious loss of true shot-change indications for the majority of film material.

4.2. Instrumentation of movement protection

Successive integrated frame difference signals are stored in a bucket-brigade delay-line which acts as an analogue shift register (see Fig. 4).

The signal is represented by a charge which is passed from one storage capacitor to the next by clock pulses at frame rate. At any time there are, therefore, five successive integrator outputs available for comparison.

A shot change is indicated if the voltage at D_3 is greater, by the factor P, than all the voltages at D_1, D_2, D_4 and D_5, with which it is compared.

5. Practical problems

The detector as described detects shot changes in signals from electronic cameras with a high success rate. Film shot changes, however, are rarely ideal and may be missed unless refinements are made. Three kinds of problems are common.

5.1. Dark scene

Under-exposed camera original film, or film of very dark scenes, contains changes from one dark scene to another which produce such low integrator outputs that the comparator output is too low to provide a reliable indication. This can be solved by applying automatic gain control to the incoming video signal so that the mean level is maintained constant. If the time constant of the gain compensation is made long compared with a field period, no interference with shot change detection will be caused by the resulting slow changes of gain occurring with changes of scene content. Alternatively, the incoming video signal to the detector may be logarithmically related to the linear signal from the telecine head-amplifier by means of a logarithmic amplifier. This logarithmic video signal represents density changes in the film and, to a first approximation, these remain constant whether the film is under or over-exposed. This last method was the one adopted for the final detector.

5.2. Mean brightness errors

When an 'A roll, B roll' print is made the printer light valve is opened and closed at the beginning and end of each shot. Sometimes the valve does not open sufficiently fast and, in the resulting print from a negative, the first frame of each shot is lighter than the remainder of that shot. This effect is shown in Fig. 7(*a*). The valve may also start to close too early at the end of a shot, with the result that the last frame is also lighter than the rest. Similar errors in mean brightness also occur when the film is joined with tape which covers the frames before and after a shot change.

The detector, as described so far, would register the changes in mean brightness occurring before or after a shot change; this is illustrated in Fig. 7(*b*). The shot change could be mistaken for movement and no indication would be produced. This problem may be overcome by differentiating the filtered difference signal. Waveform 7(*c*) shows how mean brightness information is then substantially confined to the field-blanking periods, and is thus ignored by the integrator which is reset to zero during these periods.

Very little shot change information is lost by ignoring mean brightness in this way since mean brightness is frequently nearly constant.

5.3. Splice marks

Most methods of splicing film leave marks on either side of the join, extending a short distance into the image area of the film. The effect of these marks is that the frames immediately before and after the splice differ

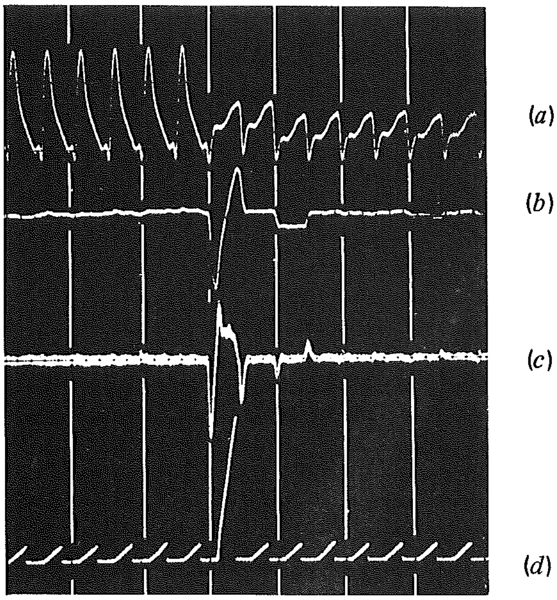

Fig. 7 - Printer errors
(*a*) Filtered video input (*b*) Difference between fields
(*c*) Differentiated difference
(*d*) Integrated (rectified) differentiated difference

slightly from adjacent frames. The movement protection circuit therefore may interpret this information as movement, and inhibit the output.

Fig. 8(*a*) shows the video signal which results from a typical cement splice involving an overlap of about 2 mm with 16 mm film. The spurious outputs due to the splice are clearly visible in Figs. 8(*b*) and 8(*c*). If no precautions are taken, the integrator output which results is as shown in Fig. 8(*d*). It will be seen that there are increased integrator outputs corresponding to film frames on either side of the splice, and that these are likely to be interpreted as motion, causing the movement protection logic to operate. This problem arises with almost all forms of splices, including thermal butt welds which often leave heat stains extending into the image area.

Since such marks are usually confined to reasonably well defined areas at the top and bottom of the image, their effect can conveniently be eliminated by inhibiting the integrator during the scanning of the top and bottom 20% of the image. In the detector this is carried out by lengthening the interval during which the integrator is reset to zero.

6. Performance and limitations

The typical performance which is regularly obtained when the detector is used in conjunction with a flying-spot telecine is such that 98% of all true shot changes are detected, 2% are missed and there are 5% spurious indications. The missed shot changes are usually due to rapid movement occurring just before or just after a shot change, causing the movement protection to operate and inhibit the shot-change indication.

It should be noted that in its present form the detector can only be used when the telecine machine is rigidly locked at 25 film frames per second to the synchronising pulses of a 50 fields-per-second television system, so that each complete film frame is scanned in exactly two television fields. A modification to the integration intervals, so that they occur correctly timed in relation to the scanning of film frames, would be necessary if the detector were to be used in conjunction with a 60 fields-per-second system, or with a telecine which was not locked and frame phased to the television system.

Problems have been encountered when the detector is used in conjunction with pre-programming equipment due to spurious operation during the run-up and stopping of the telecine and during reverse running. These have been solved by inhibiting the output from the detector unless the telecine machine is running forward and is correctly synchronised at normal speed. The detector cannot detect fades or dissolves and, when these occur, the telecine must be stopped and the shot-change information inserted by hand. If many fades or dissolves are known to be present, the preparation of a frame-cue tape is probably still the better method of ensuring the accurate timing of colour correction changes.

7. Conclusions

A shot-change detector has been developed and used for almost all pre-programming operations during the last year and has, by its high detection success rate, virtually eliminated the need for the preparation of frame-cue tapes for normal types of film. The reduced handling of the film has not only saved time and cost, but reduced the problem of dust accumulation which is particularly troublesome when reproducing negative film directly in a telecine.

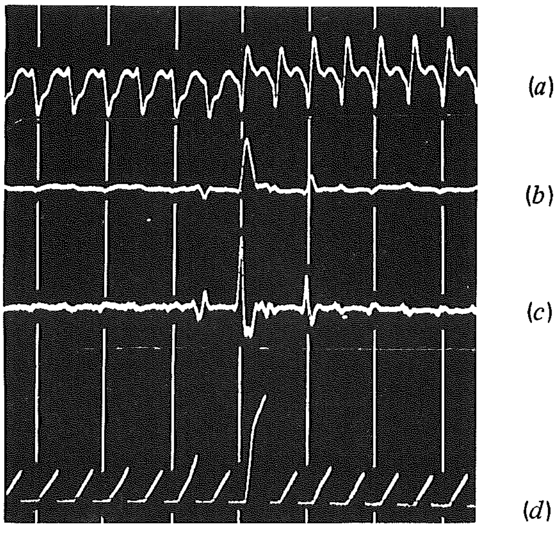

Fig. 8 - Splice marks
(*a*) Filtered video input (*b*) Difference between fields
(*c*) Differentiated difference
(*d*) Integrated (rectified) differentiated difference

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